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Influence of pea hulls on the twin screw extrusion-cooking process of cereal mixtures and the physical properties of the extrudate

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A b s t r a c t. The aim of the study was to determine the influence of the proportion of pea hulls, moisture, the barrel temperature and the diameter of the die, in the course of the process along with the possibilities for stabilising the extrusion-cooking conditions and the physical extrudate properties. Pea hulls ranging from 20 to 80% give the correct stabilisation in extrusion-cooking conditions and obtain a range of varied products with different physical and functional properties. An increase of pea hulls in extruded mixtures leads to a lowering of the radial expansion ratio and an increase in specific density, a worsening of the extrudate's texture, a decrease in the water solubility index of dry mass (WSI) and a lowering of the water absorption index of the extruded products (WAI). An increase in processing temperatures in the range of 120-220 C contributes to a slight increase in the radial expansion ratio, a lowering of the extrudate's specific density, an improvement in product crispness and an increase of the WSI. The moisture (20-26%) generates the product's structure with only a slight expansion and causes changes in the extrudate's WSI and WAI.

K e y w o r d s: extrusion-cooking, pea, cereals, physical properties

INTRODUCTION

Ailments attributable to civilisation – amongst which are diseases of the circulatory system along with cancer and obesity – are a very serious problem for the modern world. The background to these disorders is, among other things, poor eating habits and poor life-styles. An increase in meat consumption and the consumption of highly refined carbohydrates and fats which were, up until very recently, seen as a positive phenomenon and proof that society was becoming richer, have brought about unfavourable health results. For some time now, specialists in nutrition have been postulating an increase in the consumption of cereal products high in dietary fibre which are at the same time a valuable source of biologically active compounds, vitamins and minerals. Our earlier studies [5-7] showed that in order to introduce food products with high dietary fibre components, extrusion technology can be successfully applied. The possibilities for obtaining new carriers for dietary fibre by applying extrusion technology are the subject of this study.

MATERIALS AND METHODS

The basic raw materials used in the study were commercial corn semolina and pea hulls var. Opal (Table 1). Kitchen salt added to all mixtures, amounting to 1%, was the raw material used to impart taste and texture. All the raw materials were ground up until the correct degree of diminution was obtained (Table 2).

Mixtures were prepared from the above mentioned raw materials according to the experimental model elaborated (Table 3). The mixtures were wetted to the required moisture and mixed in a drum mixer; then conditioned for 12 h at room temperature. A sample prepared in such a way was then subjected to extrusion. A twin-screw 2S 9-5 extrusion-cooker made by the Metalchem Company, Gliwice with counter-rotating conical screws with a rotation speed of 72 rpm was used for the trial. The variable parameters of the extrusion-cooking process were as follows: raw material composition of the mixtures, moisture of the raw material, temperature distribution of the barrel, die diameter (Table 3). The extrudates obtained were analysed with respect to their physical properties viz: the radial expansion ratio by Rzedzicki *et al*. [7], specific density by Rzedzicki *et al.* [7], texture by Rzedzicki [4], water absorption index (WAI) by the Jao drip method [2], water absorption by the centrifugal method and the water solubility index of dry mass (WSI).

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T a b l e 1. Chemical composition (%) of the raw materials (d.b.)

Component	N – free extract	Protein (N x 6.25)	Fat	Crude fiber	Ash
Corn semolina	86.01	11.11	1.01	0.45	1.32
Pea hulls	44.53	15.55	1.75	33.39	4.78

T a b l e 2. Sieve analysis of components

Fraction (mm)	Corn semolina	Pea hulls
	(%)	
>1.6	-	1.8
1.6-1.2	3.8	22.2
1.2-1.0	22.6	15.5
1.0-0.8	26.8	18.9
0.8-0.5	29.0	19.1
0.5-0.265	14.8	12.7
0.265-0.1	1.6	6.6
<0.1	1.4	3.2
of fractions <0.5	17.8	22.5
Mean diameter (mm)	0.82	0.89

The extrudates were also subjected to studies of their microstructure by scanning with an electronic microscope. Studies on the microstructure were carried out at the Institute of Animal Reproduction and Food Research of the Polish Academy of Sciences in Olsztyn by an electronic scanning microscope - JSM 5200.

RESULTS AND DISCUSSION

The present studies have shown that by using twin-screw extrusion-cooking, it is possible to process cereal mixtures with the addition of pea hulls by up to 80%. It is not possible to add higher amounts of pea hulls. Too low a density of this component does not allow the extrusion-cooker to be filled and does not guarantee stable conditions for

T a b l e 3. Model of the experiment

Sample	Component (%)		Moisture (% g g^{-1})	Temperature (°C)	Die diameter (mm)
	Corn semolina	Pea hulls			
1	80	20	14	130/160/200/180/130	6
2	70	30	14	130/160/200/180/130	6
3	60	40	14	130/160/200/180/130	6
4	50	50	14	130/160/200/180/130	6
5	40	60	14	130/160/200/180/130	6
6	30	70	14	130/160/200/180/130	6
7	20	80	14	130/160/200/180/130	6
8	80	20	17	130/160/200/180/130	3.2
9	70	30	17	130/160/200/180/130	3.2
10	60	40	17	130/160/200/180/130	3.2
11	50	50	17	130/160/200/180/130	3.2
12	40	60	17	130/160/200/180/130	3.2
13	60	40	14	130/160/200/180/130	3.2
14	60	40	17	130/160/200/180/130	3.2
15	60	40	20	130/160/200/180/130	3.2
16	60	40	23	130/160/200/180/130	3.2
17	60	40	26	130/160/200/180/130	3.2
18	60	40	14	80/100/120/100/130	3.2
19	60	40	14	100/120/145/125/130	3.2
20	60	40	14	120/140/170/150/130	3.2
21	60	40	14	140/160/195/175/130	3.2
22	60	40	14	160/180/220/200/130	3.2

extrusion-cooking. In such conditions, material in the extruder scorches leading to flow blockages and process breakdown. The variable share of pea hulls within the range of 20-80% together with variable process parameters enables various products with extremely varied physical and functional properties to be obtained. An increase in the rate of pea hulls in the material processed influences the radial expansion ratio and product specific density considerably (Fig. 1). With a 20% share of pea hulls, excellent snacks, soft in structure and of very low density can be produced for direct consumption. A higher increase in the fibre component from 20 to 30% results in a lowering of the radial expansion ratio by about 50% and an increase in the specific density by as much as 114%. Products with a 40% share of pea hulls are characterized by a relatively hard and low expanded structure. They are hard, crunchy snacks which can still be used for direct consumption as snacks with a high salt content. Any further increase in the proportion of pea hulls in the mixtures rapidly decreases the radial expansion of the products and rapidly increases their specific density. Extrudates with a pea hull share of 50-60% are not suitable for direct consumption. They are very hard and compact, but they can be excellent half-products for the production of breakfast cereals, grits and semolina. Extrudates with a 70% - 80% inclusion of pea hulls are particularly characterised by a very low radial expansion ratio of 1.3 (die 6 mm) and a high specific density equal to, respectively, 885 kg m^{-3}.

The extrusion of mixtures with a moisture of 17%, using dies with a diameter of 3.2 mm (Fig. 1) allows products characterised by slightly more favourable physical properties to be obtained. It is to be expected that an almost double decrease in the diameter of the die should markedly improve extrudate properties as can be observed in high-starch extrudates. Unfortunately, extrudates with an increased level of dietary fibre do not follow this pattern. Rzedzicki *et al.* [8], extruding maize semolina with a 0-30% addition of crushed lentils noted the decidedly lower density and higher level in the radial expansion of those snacks, obtained by using a die with a diameter of 4 mm as compared to analogous products obtained with the use of a die with a diameter of 5 mm.

The influence of the moisture of the raw material and the process temperature on the specific density and radial expansion ratio was also analysed (Fig. 2). In this latter case, a mixture with a 40% pea hull content and a die with a diameter of 3.2 mm were used. It was found that despite an increase in the moisture of the raw material from 14 to 26% a decrease in the radial expansion ratio was caused from, respectively, 4.09 to 2.44 and an increase in the specific density, respectively, from 434.9 to 688.9 kg m^{-3}. Balandran-Quintana *et al.* [1] when extruding leguminous raw material-bean flour at the changeable moisture of 18-22% – obtained products of the best quality characterised by a high radial expansion rato and of low specific density using higher of moisture in the raw material equal to 22%. These last authors claimed that with the increasing moisture of the raw material, the viscosity of the material liquefied in the extruder decreases, resulting in a decrease in the degradation of the starch polymers; this in turn, allows us to obtain products with better physical properties, more expanded and with lower density. It should be borne in mind that such behaviour is often observed in high-protein extrudates and is related to the extension of the time during which the raw material is retained in the extruder.

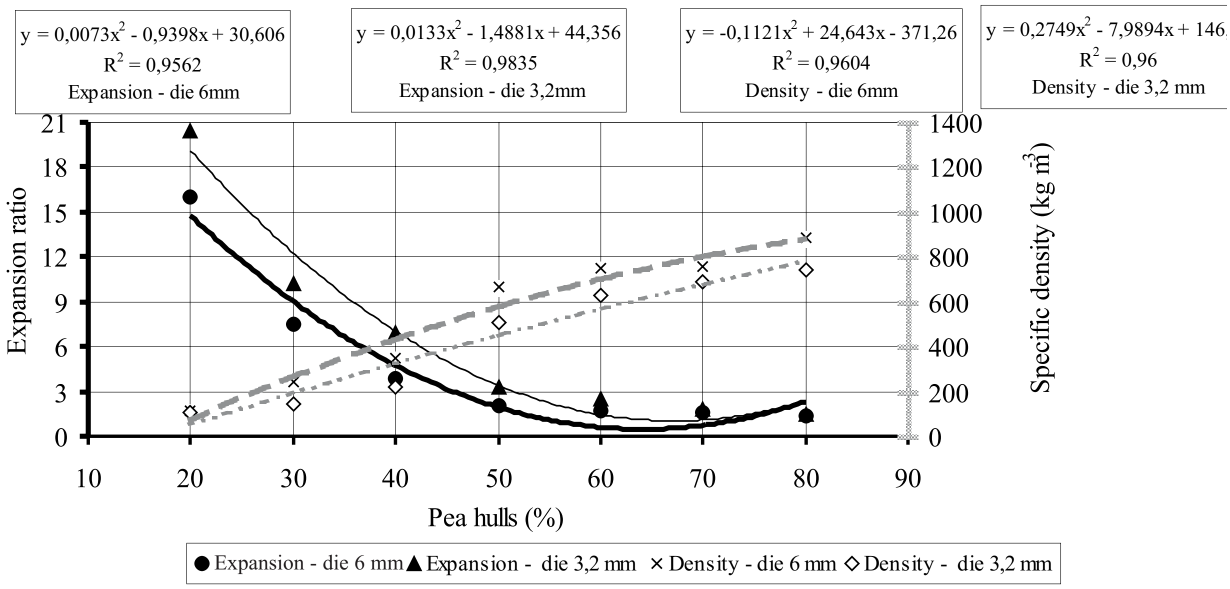


Fig. 1. Influence of the addition of pea hulls on the radial expansion of the extrudate and the specific density (die diameter 3.2 and 6 mm, moisture, respectively 17 and 14%, temperature – 200°C).

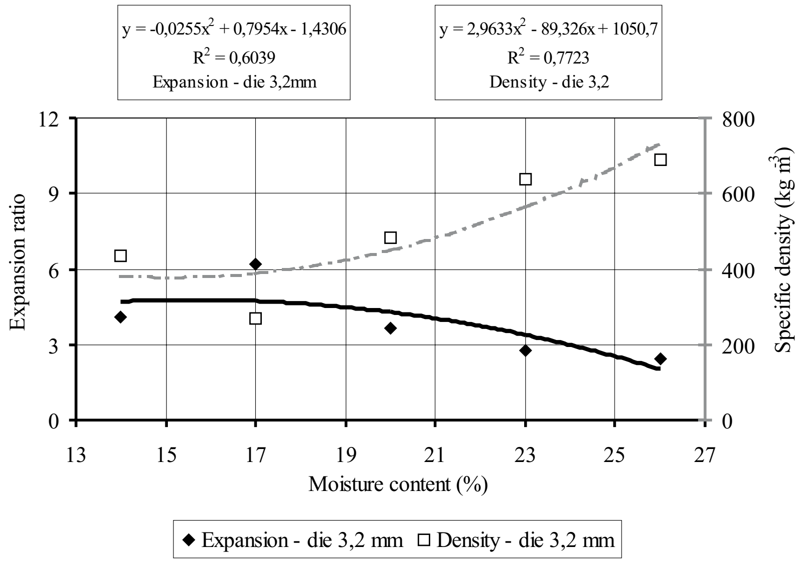


Fig. 2. Influence of the moisture of the raw material on the radial expansion of the extrudate and the specific density (die diameter – 3.2 mm, temperature – 200 C, rate of pea hulls – 40%).

The temperature of the process, when such mixtures are used, exerts only a slight impact on the physical properties of the extrudates (Fig. 3). With an increase of extrusion temperature from 120 to 170°C, we can observe a slight increase in the expansion ratio from 3.11 to 4.06 and, at the same time, a slight decrease in the extrudate's specific density from 652.68 to 480.05 kg m^{-3}. A further increase of temperature from 170 to 220°C seemed not to have any significant influence on the physical properties discussed. The influence of the extrusion temperature on the extrudate's physical properties was also studied by Balandran-Quintan *et al.* [1]. These last authors stated that an increase in the bean flour extrusion-cooking temperature (moisture of 18 and 22%) from 140 to 180°C contributed to an increase in the radial expansion of the extrudates from about 1.1 to about 1.7 and to a lowering of their specific density from about 0.77 to about 0.61-0.67 g cm^{-3}.

Studies of WSI and WAI for the products discussed were carried out in accordance with the generally accepted methodology using a centrifuge overload of 2200 g. It was

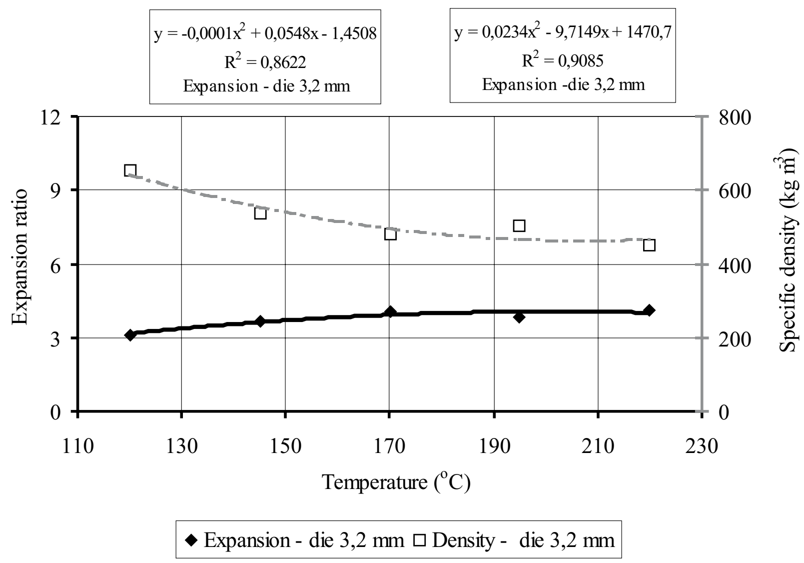


Fig. 3. Influence of the barrel temperature on the radial expansion of the extrudate and the specific density (die diameter – 3.2 mm, moisture – 17%, rate of pea hulls – 40%).

observed that an overload of 2200 g did not allow separation of the supernatant which influenced both the accuracy of the measurement and the scatter of results. This issue requires further study. When analysing WSI values for maize extrudates with an inclusion of pea hulls, an inversely proportional relation between the WSI value and the share of the high-fibre component can be observed (Fig. 4). With an increase in the pea hull share from 20 to 80%, WSI values changed from 15.85 to 11.63% in the case of extrudates obtained at 14% raw material moisture and a die with a diameter of 6 mm.

The values of WSI are conditioned also by other process parameters, among other things, die diameter, raw material moisture and extrusion temperature. It was found that an increase in the raw material moisture from 14 to 26% caused a decrease in the WSI values from 13.57 to 9.97% (Fig. 5). Similar tendencies were observed by Colonna *et al.* [2] and Smith [9] who studied solubility in the dry mass of maize extrudates. These last authors found that as a result of an increase of raw material moisture content, the solubility of the product's dry mass decreases. Increasing moisture in the raw material processed results in the lower viscosity of the

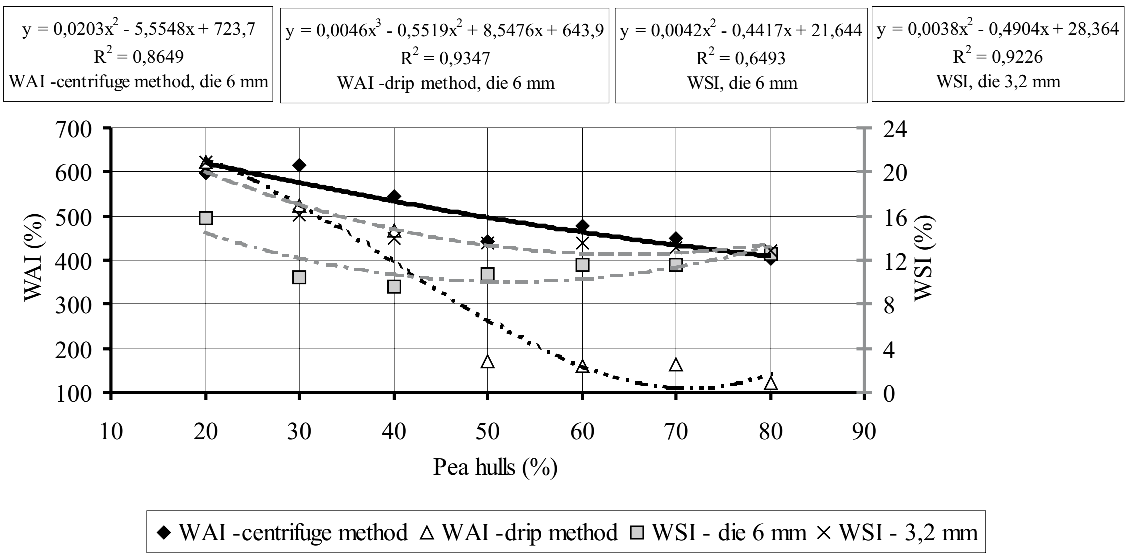


Fig. 4. Influence of the addition of pea hulls on the water absorption index (WAI) and the water solubility index of the extrudate (die diameter – 6 mm, moisture – 14%, temperature – 200°C, die diameter – 3.2 mm, moisture – 17%, temperature – 200°C).

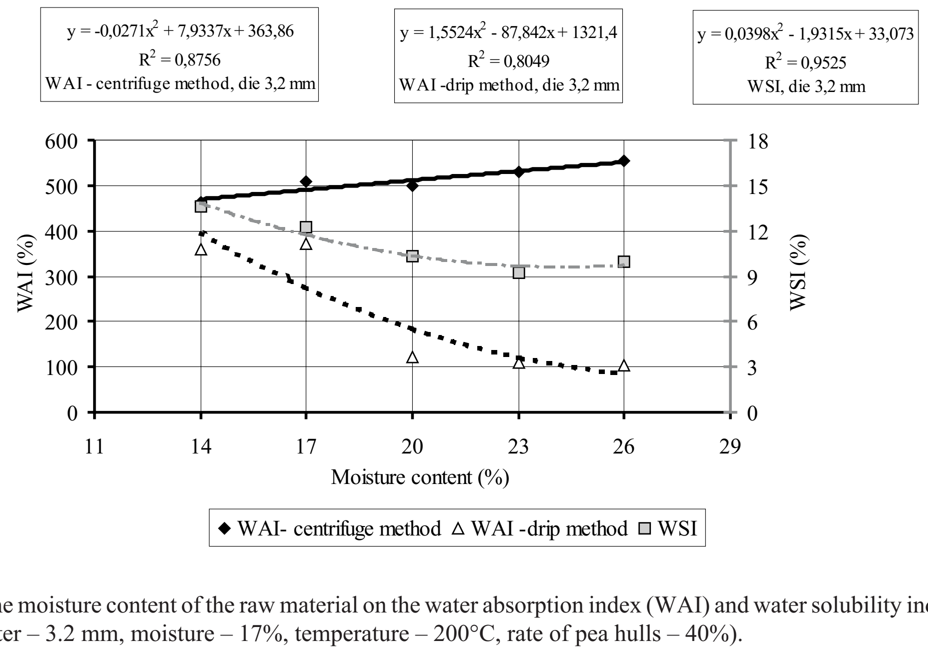


Fig. 5. Influence of the moisture content of the raw material on the water absorption index (WAI) and water solubility index (WSI) of the extrudate (die diameter – 3.2 mm, moisture – 17%, temperature – 200°C, rate of pea hulls – 40%).

mass liquefied in the extrusion-cooker and thus the intensity of impact of the shearing forces on the material processed is lower which in turn decreases the degree of dextrinisation of the starch polymers influencing the values of WSI. Also, the die diameter exerts a considerable influence on the water solubility index of the dry mass. When extruding raw materials with a moisture of 17% and using a die with a diameter of 3.2 mm, we obtain a product characterised by considerably higher WSI values. A smaller die diameter causes an increased reverse flow in the barrel of the extrusion-cooker and contributes to the extension of the time period during which the material is kept in the extruder. Any higher raw material moisture lowers the viscosity of the liquefied mass and also deepens the reverse flow. The length of time during which materials are kept in the cylinder of the extruder together with the influence of high temperatures and the pressure and shearing forces, intensifies the starch chain depolymerisation processes which, in turn, contributes to an increase of the WSI values of the extrudates.

The studies carried out showed that in the case of extrudates with an increased content of dietary fibre, there is a slight dependence between process temperature and the value of WSI (Fig. 6). As a result of temperature increases from 120 to 220°C, the value of WSI increases only from 10.04 to 11.22%. Studies by Balandran-Quintan *et al*. [1] have also shown that when extruding bean flour, with an increase of process temperatures from 140 to 180°C, an increase in the WSI values of the products from about 17.5 to 22.5% was noted.

Studies on water absorption by extrudates were also carried out by the Jao drip method [3] and the centrifuge method. When analysing WAI values for extrudates with the inclusion of pea hulls (Fig. 4), we observe an inversely proportional relation between the inclusion of a high level of the fibre component and the water absorption of the product. An increase in the share of pea hulls from 20 to 80% lowers extrudate water absorption from 598.7 to 403.7% according to the centrifuge method and gives a decrease from 622.4 to 119.6% when using the drip method.

The WAI values of the extrudates are also influenced by other process parameters. Extrusion carried out with the application of a die with a smaller – 3.2 mm diameter enables products with lower water adsorption to be obtained. The use of a die with smaller diameters extends the time period during which the material remains in the extruder. The length of time under the influence of high temperature, pressure and shearing forces conditions a higher degree of the processing of the liquefied mass. According to Smith [9] and Colonna *et al*. [3] the increased degradation of the molecular mass of the starch polymers could be the reason for lowered extrudate water absorption.

Smith [9] is of the opinion that the water absorption of products increases with the increase in process temperature up to a level at which the total gelatinisation of the starch takes place. A further increase of temperature and the progressive depolymerisation of the amylose and amylopectine lead to a decrease in the capability of the product to absorb water. Similar tendencies can be observed when analysing Fig. 6. In determining water absorption by Jao's method, maximum values were noted for those products processed at a temperature of 145°C. It is to be expected that where products have an inclusion of pea hulls, only a high processing temperature will enable the total gelatinisation of the starch. The use of a lower extrusion temperature, i.e., 120°C, seemed insufficient for the total liquefaction of the starch granules.

The results presented in Figs 4-6 showed high discrepancies in the WAI resulting from the various methods for determining water absorption. It should be stated that the water absorption of extrudates – determined according to Jao's drip method [3] – was far lower than the water absorption determined by the centrifuge method. In trials, differences reach as much as 450%. Different trends resulting from different methods of determining water absorption were observed when studying WAI as a function of raw material moisture (Fig. 5). The results obtained by means of the drip method proved that water absorption of the products decreases with the increase in raw material moisture. The 15 min time period applied for hydration seems insufficient for the total hydration of any unground extrudate. The above was confirmed by Rzedzicki *et al*. [8]. The increase in raw material moisture levels which favours the creation of a hard and compact product structure, contributes to the lowering of extrudate hydration dynamics. In consequence, the products are then characterised by low WAI values. Water absorption determined by the centrifuge method for ground extrudate, increases with the increase in raw material moisture (Fig. 5). In interpreting the results for water absorption, we have to bear in mind that the drip method shows how much water could be held by the product during a 15 min period. The centrifuge method shows what the highest amount of water is which could be held by the ground extrudate mass.

Extrusion process conditions as well as the composition of the mixture influence extrudate texture considerably. However, the low values of destructive energy were still somewhat surprising. With an increase in the pea-hull proportion in the mixture (Fig. 7), a decrease in destructive energy was observed. The product is less gluey and more susceptible to breaking up. The values of destructive energy obtained ranged from 0.61 to 0.25J g^{-1}. Extrusion temperature (Fig. 8) influences texture non-typically. A clear, decreasing tendency was observed with an increase in temperature. Usually during the extrusion of high-starch mixtures, a product is at its most compact at a temperature representing total starch gelatinisation; a further increase in temperature leads to a decrease in destructive energy. These extrudate textures are conditioned by raw material moisture but only to a very low degree (Fig. 8). Changes in moisture ranging from 14-26% did not significantly change the susceptibility of the product to being broken up. The lowest values of destructive energy were observed for a moisture of 17%.

The extrudate samples selected were also subjected to examination by microscope (Fig. 9). Results of trials for extrudates with a high (40%) pea-hull inclusion were presented as an example. These products are characterised by a relatively hard structure and a low expansion degree which coincides with the results of the expansion and specific density measurements. The several large air cells visible in the photos of the micro-structure are surrounded by relatively thick walls. At x1000 magnification however, we can see that in the thick walls of the air cells there are numerous small pores, a few µm in size. These can produce products using a 40% inclusion of pea hulls, a texture still acceptable to customers. Such products are hard, crusty snacks which can be used for direct consumption.

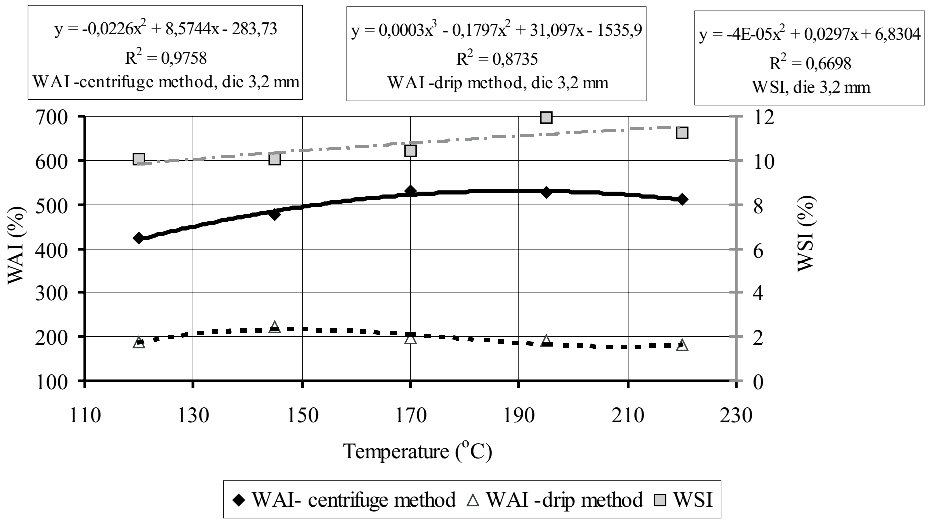


Fig. 6. Influence of barrel temperature on the water absorption index of the extrudate (WAI) and the water solubility index of the extrudate (WSI) (die diameter – 3.2 mm, moisture – 17%, rate of pea hulls – 40%).

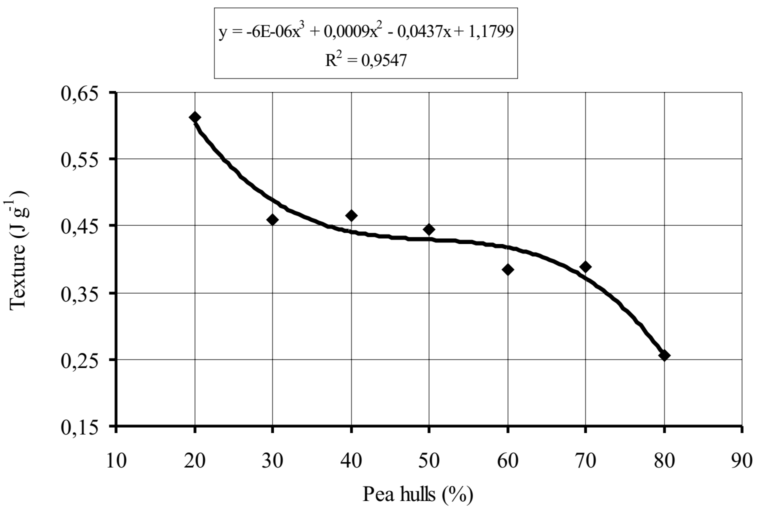
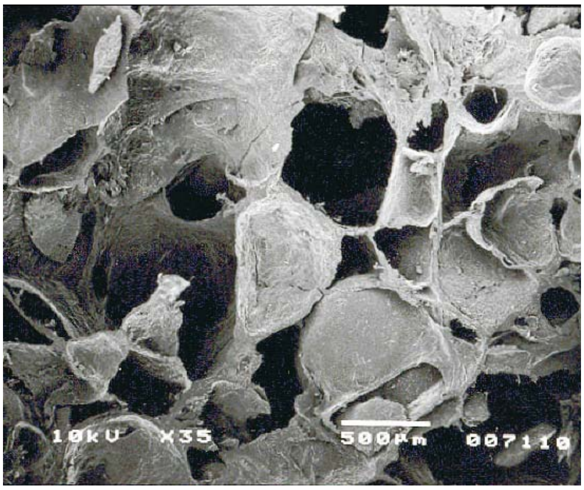


Fig. 7. Influence of the addition of pea hulls on the texture of the extrudate (die diameter – 6 mm, moisture – 14%, temperature – 200°C).



CONCLUSIONS

1. The studies carried out proved that pea hulls used in an amount of up to 80%, can be a valuable high dietary fibre component for the production of extrudates.

2. The addition of up to 40% of this component is advised for such products as snacks and hard chips; an application of 50-60% of pea hulls in cereal mixtures enables production of extrudates for breakfast cereals, grits and semolina. Extrudates with a 70-80% addition of pea hulls can be a valuable half-product for further processing.

3. An increase in the content of pea hulls in the extrudate causes *inter alia*: a lowering in the radial expansion ratio, an increase in the specific density of the extrudate, a lowering in the water solubility index of dry mass as well as a lowering of the water absorption index of the extrudate.

4. An increase in the moisture of the processed raw material causes *inter alia*: a decrease in the radial expansion ratio, an increase in the specific density of the extrudate, a lowering of WSI and an increase in the WAI of the ground products.

5. An increase in the temperature during the extrusion process contributes *inter alia* to: an increase in the radial expansion ratio, a lowering of the specific density of the extrudate and an increase in the WSI.

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